A Multi-Pass Median Filter Technique to Remove Ambiguities in Retrieved Wind Fields From Spaceborne Scatterometer Data

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ABSTRACT

An automated median filter-based ambiguity removal algorithm is used because of its simplicity and computational efficiency. The algorithm requires an initial wind field. Consequently the performance of the algorithm depends largely on the accuracy of the initial wind field compared to the true wind field. Usually, an initial wind field consisting of the highest ranked retrieved wind vectors is used. However, we found that this does not result in the best performance. In this paper we present a technique called the multi-pass median filter algorithm. The technique gives superior performance to the conventional median filter algorithm by generating a better initial wind field.

INTRODUCTION

Spaceborne scatterometers such as SeaWinds [1,2] measure backscattering coefficients σ from the ocean surface at multiple incident angles and polarizations. The scatterometer data is grouped in a wind vector cell then used to retrieve ocean surface vector winds using a geophysical model function and a maximum likelihood retrieval technique [3]. The harmonic dependence of backscattering coefficient on wind direction results in multiple solutions per each wind vector cell [4]. Up to 4 vector solutions (ambiguity vectors) are kept per wind vector cell. Each wind solutions within a cell is ranked based on its maximum likelihood value. Usually, there is one "true" solution and the remaining ones are the aliases. In most cases, the two highest ranked solutions have similar wind speeds but are about 180 degrees apart in direction. Furthermore, analysis of past scatterometer derived wind vectors and simulation results have found that the two highest ranked solutions are the closest to the true wind direction in about 80-90% of the time. The best solution from a set of wind vectors is selected for each cell. This procedure is called ambiguity removal or dealiasing [5].

MEDIAN FILTER BASED AMBIGUITY REMOVAL ALGORITHM

An ambiguity removal algorithm based on the median filter was initially developed for NSCAT because of its simplicity, computational speed, and accuracy [6,7]. A median filter window size of N×N is applied to a center wind vector cell ij with k ambiguity vectors. The vector form of the median filter algorithm can be written as

$$E_{ij}^{it} = \sum_m \sum_n \left\| A_{ij}^k - U_{mn}^{it} \right\| \qquad (1)$$

For an iteration it, a vector A_{ij}^k which minimizes E_{ij}^{it} is chosen by the algorithm and stored. This procedure is repeated until all wind vectors cells have been filtered. Then before the next iteration, we let $U_{ij}^{it+1} = A_{ij}^k$. The iteration continues until convergence is achieved. Note that an initial wind field U_{ij}^0 is needed. The performance of the median filter depends greatly on the initial wind field. In the autonomous implementation, an initial wind field is comprised of those vector wind solutions with the highest rank [7]. However, initializing the wind field with the highest ranked solutions may not give the best performance.

MULTI-PASS AMBIGUITY REMOVAL ALGORITHM

Recently, we have developed a technique called the multi-pass median filter ambiguity removal algorithm. The implementation is very simple. In the first pass, the median filter selection is limited to the two highest-ranked solutions ($k\_max = 2$). The median filter is applied to all cells and iterated until convergence is achieved. Note that for a given wind vector cell, the two highest ranked solutions are similar in wind speed but approximately 180 degrees apart in direction. Thus, the key idea behind the multi-pass median filter technique is that by limiting the selections to the two highest-ranked solutions the resulting wind field would contain only the correct or alias solutions with 180 degree difference. In the second pass, the selected wind indices from the first pass are used to initialize

the wind field. For this pass, the median filter selects from all solutions in a cell as in the original autonomous median filter ambiguity removal algorithm. Again, the median filter is applied to all cells until convergence is achieved.

SIMULATION RESULTS

The algorithm was tested with simulated wind retrieval data using a SeaWinds scatterometer measurement geometry. A key parameter in the simulation is how much noise to add in the backscattering coefficients for a given wind speed u and direction χ. A model we used to simulate noisy backscattering coefficients from the ocean surface may be simplified to

$$\sigma(u,\chi)=\sigma'(u,\chi)[1+Kp\ n(0,1)] \qquad (2)$$

where the prime indicates a noise-free backscattering coefficient, n(0,1) is a zero-mean, univariant, Gaussian random process, and Kp is defined as

$$Kp = \frac{\sqrt{\mathrm{var}(\sigma)}}{\sigma'} \qquad (3)$$

The Kp is determined from the geophysical modeling error (Kpm), communication noise (Kpc), and instrument/attitude control error (Kpr). It is a function of wind speed. First, we let Kp = 0.86. This Kp value is the Kp at 7 m/sec wind speed. Figure 1 shows a small area of a wind field used by the simulation program to generate the backscattering coefficients. This is the true wind. In other words, if noise-free backscattering coefficients are used in the wind retrieval followed by a perfect ambiguity removal algorithm then the wind field of Figure 1 is the result. In Figures 2 and 3, the wind fields produced by the usual median filter algorithm and the multi-pass median filter algorithm are plotted, respectively. These are for 25km x 25km wind vector cell retrievals. It is clearly evident that the multi-pass algorithm is superior in performance. In Figure 4(a), the ambiguity removal skill result for Kp = 0.86 is plotted as a function of cross-track distance from spacecraft nadir. The ambiguity removal skill is defined with respect to the closest solution: the algorithm is considered a success if a vector with a direction closest to the true wind is picked. The result shows about a 10% improvement over the original median filter method. The result shown is for 10 orbits of data. Each data point is averaged over about 11000 wind vector cells. Figure 4(b) shows the result for the case of Kp = 0.55. The result is averaged over 5 orbits of data. Each data point for this example is averaged over about 5500 wind vector cells. The improvement is less than 2%. It is evident in Figure 4(b) that when the usual median filter is highly accurate, then there is little difference in the two techniques. Further improvements to achieving an autonomous ambiguity removal algorithm may require a model based ambiguity removal [8].

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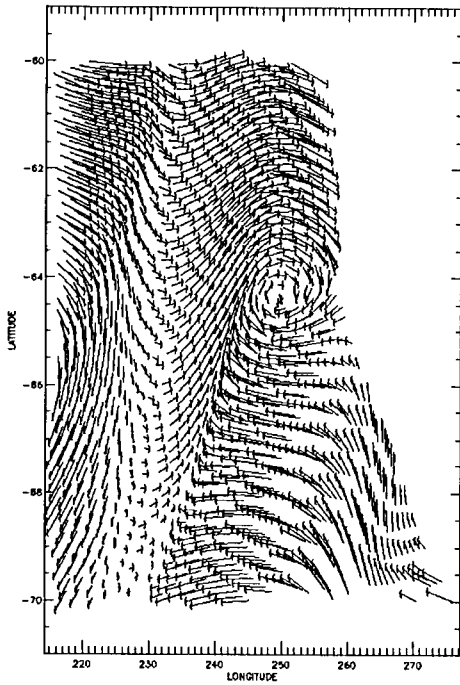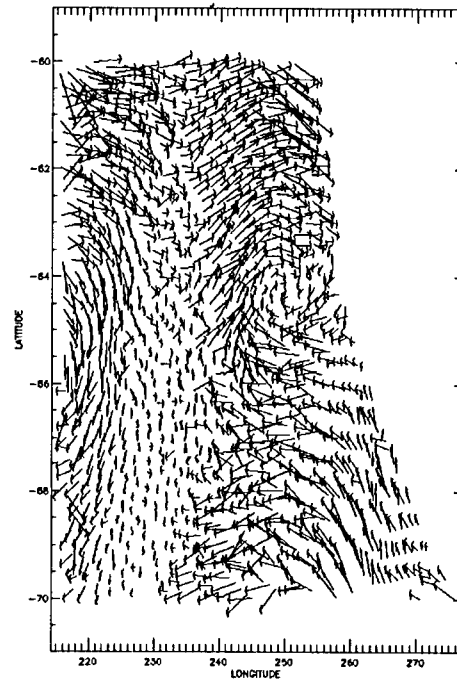
Figure 1: True wind field.

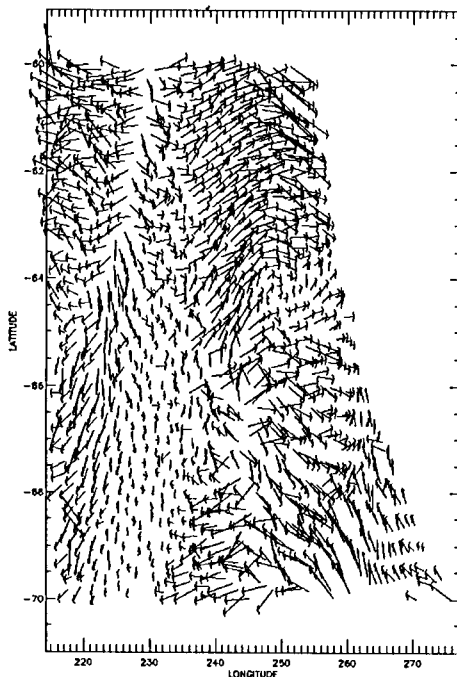Figure 3: Wind field selected by the multi-pass median filter algorithm (Kp=0.86).

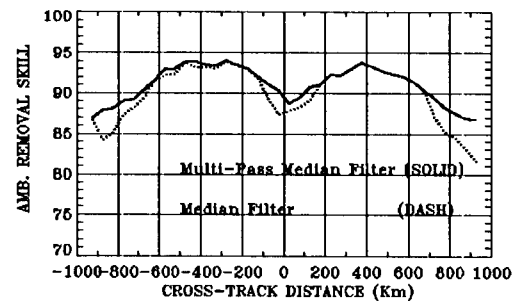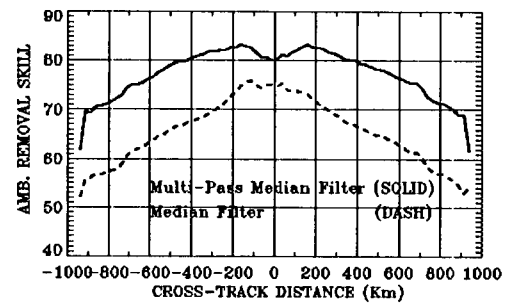Figure 2: Wind field selected by the usual median filter algorithm (Kp = 0.86).

Figure 4: (a) top, Kp = 0.86, (b) bottom, Kp=0.55